Meteorites in the desert: a review of meteoritics in Western Australia

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Abstract

The history of meteorites in Western Australia since the first meteorites were discovered near Quairading on 4 January 1884, is reviewed. Several individuals have made a significant contribution to the Collection during that period of time, so that it now comprises approximately 190 local and 120 other Australian and overseas meteorites. The science of meteorites has played and will continue to play an essential role in our understanding of the formation and evolution of the solar system. Because of the unique characteristics of a number of Western Australian meteorites, many of them have been the subject of detailed petrological and isotopic studies. The meteorites which have been recovered from the desert regions of this State represent a rich store of extra-terrestrial material which now comprises part of our heritage and will continue to contribute to our expanding knowledge of planetary science.

Out of the Sky

A meteorite is a solid body which has arrived on the earth from outer space. The name is derived from the Greek word *meteora*, which means "things in the air". Material from interplanetary space is colliding with the earth in amounts estimated at between a few thousand and a few million tonnes per year. Most of this solar system debris is too small to penetrate the atmosphere and is vaporised by frictional heating to form a "shooting star" or meteor. A few objects however, are sufficiently large to reach the earth's surface as meteorites.

Although the science of meteorites is very young man's experience with meteorites probably dates from the very dawn of the human mind. Philosophers of ancient Greece and writers of the Han Dynasty in China described meteorite falls. The sacred stone of Kaaba in Mecca to which Moslems pay homage, is apparently a meteorite. We also know that the American Indians revered meteorites, and that yearly pilgrimages were made by the Cree and Blackfeet tribes to the top of a hill in Southern Alberta on which lay the Iron Creek meteorite. The Winona meteorite was found in a stone cyst such as was used for child burials among ruins near Winona, Arizona. Some iron meteorites have been made into weapons reputed to confer supernatural powers on the bearer.

The fall of a meteorite can often be a spectacular event. On September 2nd 1967, a stone meteorite fell near Wiluna in Western Australia (McCall and Jeffery 1970). According to witnesses the sky was lit by a flash "like a welding arc—white and blue." One man saw "an object about 20 feet long throwing out balls of fire." There were reports of "a terrific rumbling noise" and "bangs up to six or seven in number." The violent explosive reports are caused by atmospheric shock waves which accompany the fragmentation of a meteorite during its passage through the atmosphere.

Most evidence suggests that the majority of meteorites are from the asteroid belt, although it is believed that some of the smaller debris encountering the Earth's atmosphere may in fact be derived from comets. Asteroids are small, solid bodies, enormous numbers of which orbit between Mars and Jupiter. The largest, Ceres, is 770 km in diameter. It has been estimated that there may be 10^4 asteroids larger than 10 km and perhaps 10^{14} larger than 1 m in diameter. The atmospheric entry trajectories and velocities of three meteorites have been determined from multiple-station meteor cameras to permit calculations of their pre-terrestrial orbits in space. These orbits resemble the orbits of known asteroids that cross the Earth's orbit.

The column of air a meteoroid must displace as it falls to earth varies as its cross-sectional area, whilst the mass of the meteoroid varies as the cube of its dimension. Thus meteoroids of several metres in diameter which weigh in excess of 100 tonnes are more massive than the column of air they displace—so the atmosphere cannot slow them down significantly. Pressure of air against the face of incoming large stone meteorites tends to break them up and a shower of small stones results. Large iron meteorites on the other hand, are much more durable and may reach the ground at velocities of tens of kilometres per second.

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Figure 1.—The Wolf Creek Meteorite Crater which is located some 106 km south of Halls Creek, Western Australia. The diameter of the crater is approximately 800 m and it is 40-55 m deep.

If a 100 tonne iron meteorite fell, its kinetic energy at impact would be enormous (perhaps $2 \times 10^{1} J g^{-1}$), and it would explode as violently as a nuclear bomb. The only explosive encounter in recent times occurred near the Tunguska River in Siberia in 1908. Some degree of mystery surrounds the devastation which occurred in this region, as no scientific expedition was mounted until 1927. A bright fireball accompanied the explosion which was heard up to 1 000 km away. Some have argued that the explosion was caused by a small comet, or by an anti-matter object, or even by a black hole.

Some 35 structures in the Earth have been identified with varying degrees of certainty as ancient meteorite explosion craters—the largest being the Arizona Meteor Crater which is 1.2 km in diameter and 140 m deep. Specimens of an iron meteorite have been recovered from the site. Twisted and deformed, these irons are called "Canyon Diablo", after a canyon which winds its way across the surrounding terrain.

The Wolf Creek crater near Halls Creek in Western Australia is an impressive structure some 800 m in diameter. It was only discovered in 1947 when it was recognised from the air. The crater is partly filled with wind-blown sand and gypsum. Shale balls, up to 136 kg in weight were recovered from the crater (Cassidy 1954), but little meteoritic material has been found. A photograph of the Wolf Creek crater is shown in Figure 1. The only other crater in Western Australia where meteoritic material has been found is at Dalgaranga, north of Yalgoo. This crater is approximately 25 m in diameter and 3 m in depth. Discovered in 1923 by Mr. G. E. P. Wellard, it has stony iron (mesosiderite) and metallic fragments associated with it, and is undoubtedly of meteoritic origin.

The Veevers Crater (Yeates *et al.* 1976) between the Great Sandy and Gibson Deserts and, more doubtfully, certain structures in the Kimberley region (Roberts *et al.* 1965), may also prove eventually to be of meteoritic origin. Small pieces of stony meteorite were found within a probable impact crater (as distinct from an explosion crater) on the Nullarbor Plain (McCall and Cleverly 1968).

History of meteoritics in Western Australia

The first recorded meteorites in Western Australia were a number of irons discovered by a policeman named Alfred Eaton, towards the end of the 19th century, when agriculture was being established to the east of the early settlement at York. These became known as the "Youndegin" meteorites after a police outpost, although they were actually collected near Pikaring Rock in the Quairading district.

While most of these meteorites were identified in the period 1884-1893, a number of other irons of similar structure were found in the same vicinity—the last in 1929. The four meteorites discovered by Alfred Eaton on January 5th 1884, were subsequently shipped to England, where they were sold to a scrap-metal dealer. Fortunately they were recognised in time and acquired by museums around the world. Youndegin I (of mass 11.7 kg), is now in the British Museum (Natural History); Youndegin II (10.9 kg), at the National Museum, Melbourne; Youndegin III (7.9 kg) at the Western Australian Museum, whilst Youndegin IV (2.7 kg), is also in the British Museum (Natural History). Other samples of the Youndegin meteorites are located in museums in Chicago, New York and Vienna, whilst a piece of Youndegin VIII was made into a horseshoe and hung for many years in a blacksmith's shop in York. In 1954 Mr E. C. Johnston presented a large 2 626 kg iron meteorite to the Western Australian Museum. Originally found in 1903 on a gravel ridge approximately 34 km south-east of Quairading, it was rediscovered by Mr Johnston whilst scrub-rolling with a World War II General Grant tank. This meteorite, which was called "Quairading", is now on display in the Museum. A detailed examination of the geographical location, microstructure and chemical composition of the Mt. Stirling, Mooranoppin, Quairading and the Youngdegin meteorites by de Laeter (1973, a), has shown that they are all members of the one meteorite shower.

Western Australia is in an extremely fortunate position with respect to meteorites. Approximately 190 have been found in this State and on an areal basis this represents a recovery rate treble that of the world average. Despite the sparse population and the relatively recent time of settlement by European man in Western Australia, there are a number of factors which have led to our excellent record in meteorite recovery:—

(i) The large regions of arid country enable meteorites to be preserved for long periods of time after falling to the earth's surface, and to be recovered more easily than in heavily vegetated terrain. Ploughed farmland also increases the possibility of finding meteorites.

(ii) As far as can be ascertained, the Aboriginal people of Australia were not interested in meteorites, either as objects of reverence or for their use as metals, whereas in many other countries with ancient civilisations, meteorites have been collected and used for a variety of purposes over the centuries.

(iii) The people of Western Australia who have presented their discoveries to the Museum for identification and display without thought of personal gain, but in the recognition that these objects are of tremendous value to science and represent part of our common heritage.

These factors have enabled Western Australia to develop an excellent meteorite collection. Not only do we have a fine collection of local meteorites, some of which are unique, but we have been able to exchange our meteorites with other Museums, so that we now have in excess of 100 meteorites from other parts of the world in our collection. The collection is administered by a Meteorite Advisory Committee, which has the responsibility of assessing proposals from scientists around the world who wish to analyse Western Australian meteorites. Under the Western Australian Museum Act of 1969, legal ownership of meteorites found in the State rests with the Crown.

The doyen of Western Australian meteorite collectors is undoubtedly Mr A. J. Carlisle. Approximately 80 meteorite specimens have been found by members of the Carlisle family. It is doubtful if anyone else in the world has been responsible for finding as many meteorites as Mr Carlisle. The Nullarbor Plain has been a happy hunting ground for meteorite collectors, and the collaboration between Mr Carlisle and Messrs W. H. Cleverly and M. K. Quartermaine, former staff members of the W.A. School of Mines, has been instrumental in enabling these meteorites to be recovered, identified and displayed. The most amazing discovery made by Mr Carlisle was in recovering a small, rare carbonaceous chondrite called "Lookout Hill". The specimen only measured a few centimetres in diameter and was covered in red soil, yet was recognised by Mr Carlisle as a meteorite, and later confirmed to be of extreme rarity.

The person who was instrumental in laying the foundation for the State's meteorite collection in the first 40 years of this century was Dr. E. S. Simpson, who from 1922 to 1939 was Government Mineralogist and Analyst. Although mostly remembered for his pioneering work on Western Australian minerals, he was also a keen meteoriticist who assiduously collected and analysed a variety of meteorites, and ensured that they were placed in museum collections (Simpson 1938). Dr. Simpson was an active member of the Royal Society and was President in 1939. It is generally conceded that the meteorite collections in Western Australia would be incalculably poorer but for the pioneering work of Dr. Simpson.

The years from 1940-1960 were barren ones in meteoritics in Western Australia. Few meteorites were recovered, and with the death of Simpson, the meteorite collections fell into disuse. In 1963 Dr G. J. H. McCall (from the Geology Department at the University of Western Australia), became interested in meteoritics, and the meteorites in the State were classified, resulting in the first Catalogue of Western Australian Meteorite Collections (McCall and de Laeter 1965). This catalogue overcame the lack of information on the various meteorite collections in the State, at a time when there was an increasing awareness of the scientific importance of meteoritic material in deciphering the early history of the solar system, and in the formation of planets. In fact shortly thereafter some of the State's meteorites were used in a study of the nuclear processes which had synthesised the element tin in stars (de Laeter and Jeffery 1965); this being the first of many scientific investigations in many laboratories around the world in which Western Australian meteorites played an important role.

At that time there were only 50 meteorites in the collection, but many of them—like the Youndegin meteorites—were specimens of the one meteorite shower. It was also of interest to note that 29 of the 50 meteorites were irons, in contrast to the world-wide figure in which only about 6% of the number of meteorite specimens are irons. This situation reflected the fact that irons are more easily

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recognisable than stony meteorites, require less sophisticated scientific techniques for proper identification, and are preserved for greater periods of time on the Earth's surface than the more readily weatherable stone meteorites. There were only three meteorites which had been recovered after they had been observed to fall. The remainder were all "finds". The small proportion of "falls" to "finds" is probably due to the sparse population of the State.

Dr McCall remained the driving force behind meteoritics in this State for approximately 10 years, in which time the collection was properly organised and many meteorites were recovered. When the Second Supplement to the Catalogue was published (McCall 1972), 93 meteorites were recorded, most of the additional meteorites being stones, many of which had been identified and classified by Dr McCall.

It was fortuitous that Dr McCall's replacement on the Geology Department staff at the University of Western Australia was Dr R. Binns. A distinguished meteoriticist, Dr Binns assumed the Chairmanship of the Meteorite Advisory Committee, and his international contacts proved invaluable in arranging for meteorite exchanges and in amending the names of some Western Australian meteorites to conform with the International Meteorite Nomenclature Committee. Meteorites are named after the nearest geographical feature to where they are found, but the Western Australian deserts are not well endowed with such features, and thus there are meteorites from the Nullarbor Plain which carry such titles as "Laundry Rock Hole", "Mulga West", "Pannikin" and "Billy Goat Donga".

Messengers from space

Nobel Prize winner, Harold Urey, once said that meteorites are the only samples of extra-terrestrial matter delivered to our doorsteps free of charge. While the genesis of meteorites is by no means fully understood, there is no doubt that they are the most primitive material we have in our possession. They have remained virtually unchanged since the time the solar system formed, and are more representative of the composition of the solar system than the highly differentiated crust of the Earth. In consequence, element and isotope abundances measured in meteorites provide some of the basic facts to be explained by astrophysical theories of the synthesis of the elements. The amount of information contained in a few grams of meteoritic material is quite remarkable.

Meteorites may be classified into three major groups—stones, irons and stony-irons; the former being by far the most abundant in number in spite of the fact that irons are often the most publicised and well-known to the layman. Mineralogically meteorites consist of varying amounts of nickel-iron alloys, silicates, sulphides and other minor phases. Stony meteorites most closely resemble terrestrial rocks and have the greatest variety in composition, colour and structure. These meteorites consist of olivine, pyroxene and plagioclase feldspars together with metallic nickel-iron and the iron sulphide troilite. One particular structural feature called chondrules divides the stony meteorites into two major sub-groups—*chondrites* and *achondrites.*

Chondrules are small, nearly spherical silicate inclusions which have been formed under melting or reheating conditions. The ordinary chondrites consist entirely of high temperature minerals and are remarkably uniform in composition. They approximate the equilibrium mineral assemblage that would be expected to develop in a rock of chondritic composition if held at moderately high temperatures (500-1 000° C) in a closed system.

The chondrules are embedded in a matrix of a similar mineralogy, and the boundaries between the chondrules and the matrix are often indistinct—the result of thermal metamorphism. Van Schmus and Wood (1967) have used a binary classification in which each chondrite is assigned a chemical group and a petrologic group on the basis of the degree of chondrule—matrix intergrowth.

A very important subset of the chondrites are the *carbonaceous chondrites,* which are grey to black in colour and consist of high temperature, anhydrous minerals embedded in a fine grained, blackish earthy matrix. The carbonaceous chondrites take their name from the fact that the matrices are impregnated with a tarry mixture of organic compounds up to 5% by weight. The presence of this low temperature material implies that they are very primitive meteorites and closely approximate the unaltered primordial material of the solar system. Although the carbon compounds do not necessarily indicate biological matter, they do closely resemble the organic molecules upon which life is based. In fact the chemical composition of the C1 carbonaceous chondrites closely match the composition of the Sun and have been used as the basis of the Standard Distribution of the elements (Anders and Ebihara 1982). This distribution is the basis for all theories of element formation in stars, (Burbidge *et al.* 1957), and without it our present knowledge of the evolution of the Universe would be greatly reduced.

The *achondrites,* as the name implies, do not possess chondrules, and are similar to terrestrial igneous rocks. They are of interest because they are broadly similar to many lunar samples, implying that they came from a part of the solar system where geological processes once operated much as they did on the moon.

Iron meteorites consist largely of nickel-iron, generally with a nickel content of 5-10% and a cobalt content of approximately 0.5%, but often contain troilite, which is an iron sulphide. In fact the high nickel content is an effective method of identifying iron meteorites. Irons consist of two metallic alloys arranged in a characteristic geometry-kamacite (6-7% nickel) and taenite (30-50% nickel). Depending upon the proportion of nickel to iron, iron meteorites are subdivided into three groups—hexahedrites, octahedrites and ataxites. Hexahedrites have 4-6% nickel occurring as kamacite, whereas at the other end of the scale, ataxites have a nickel content in excess of 12%, and consist mainly of taenite with an intergrowth mineral of kamacite and taenite called plessite.

The most abundant type of iron meteorites are the octahedrites which contain both kamacite and taenite, forming an interlocking crystal structure called the Widmanstatten pattern. If the surface of an octahedrite is polished and etched, this beautiful metallurgical pattern is revealed. An example of the Widmanstatten pattern of the Youndegin meteorite is shown in Figure 2. This structure developed during the slow cooling of meteorites from high temperatures—the kamacite plates nucleated from taenite crystals, then grew in thickness with

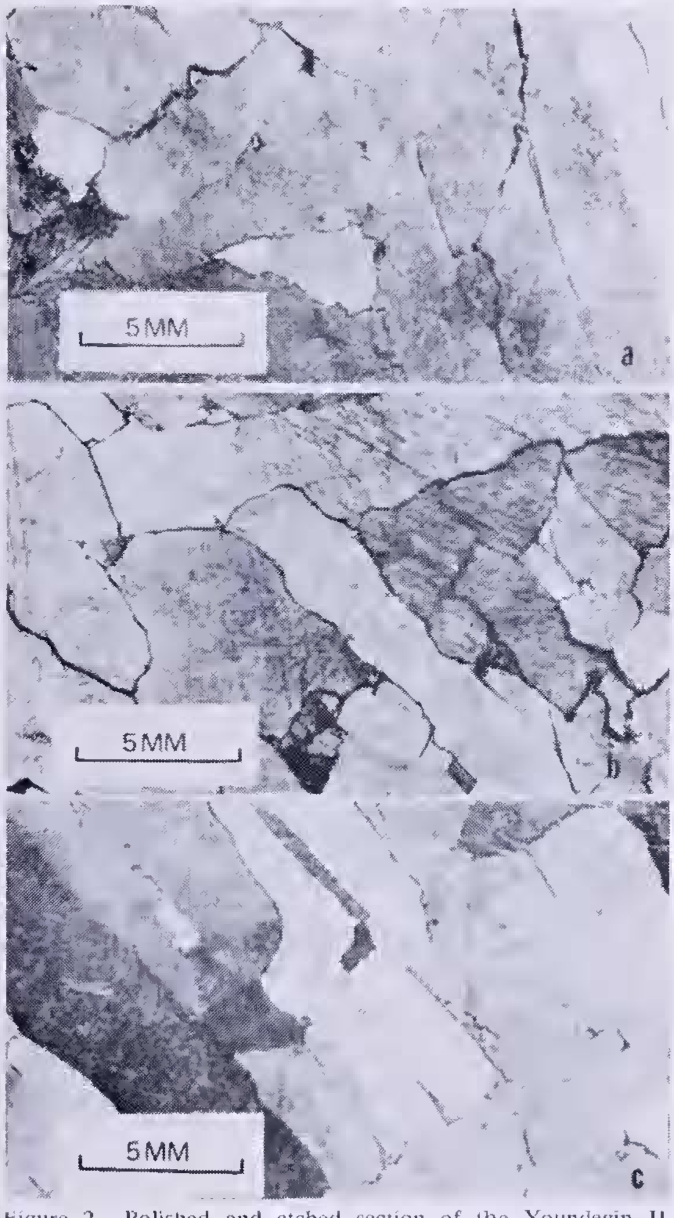

Figure 2.—Polished and etched section of the Youndegin II iron meteorite, showing the coarse Widmanstatten pattern typical of octahedrites.

the nickel contents of both the kamacite and taenite alloys changing as they adapted to new equilibrium conditions at lower temperatures. Solid state diffusion of nickel and iron atoms across the crystal faces was the mechanism which enabled the separation of the alloys to occur. Laboratory studies carried out on the diffusion rates in nickel-iron alloys have enabled deductions to be made of the declining temperatures that the octahedrites must have experienced to establish the present compositional gradients. It has been found that the octahedrites cooled through the temperature range 600 to 400° C at rates of a few degrees every million years (Goldstein and Short 1967).

The question of the number of parent meteorite bodies involved has been tackled by John Wasson and his colleagues at the University of California at Los Angeles (Scott and Wasson 1975). By analysing a number of trace elements in iron meteorites—principally gallium, germanium and iridium together with their correlation with nickel—it has been shown that meteorites cluster in chemical groups which can be interpreted as characterising a geochemical regime corresponding to a number of parent bodies. Other trace elements also show similar correlations and enable other fractionation mechanisms to be identified (e.g. Mermelengas *et al.* 1979).

The final group of meteorites are the relatively rare *stony-irons* or *mesosiderites*, which consist of silicate minerals and nickel-iron in approximately equal proportions.

Ages of meteorites and the birth of the solar system

Radioactive decay is the systematic transformation of a parent radioactive nuclide into a daughter nuclide, which more often than not is stable. If the half-life of the radioactive transmutation is known and we can measure the amounts of parent and daughter nuclides present today, we should, in principle, be able to determine the age of the material in which the radioactive nuclide occurs. The most commonly used geochronological decay scheme is based on the decay of the radioactive isotope ^{87}Rb to the stable isotope ^{87}Sr. Thus if a rock containing some rubidium was formed early in the solar system and has remained a closed system ever since, we should be able to calculate its age by measuring the isotopic composition of strontium in a mass spectrometer—an instrument which measures the abundance of the isotopes of a given element.

The age of the solar system can be measured by analysing meteorites, for these objects have been relatively undisturbed since the beginning of the solar system. Accurate measurements have been carried out on chondritic meteorites to give a consistent age of 4 600 million years, which we now accept to be the age when the cold and dark of space was transformed by crushing gravitational forces into a fiery thermonuclear inferno—which heralded the birth of a brand new star which we call the Sun.

But what was the mechanism that triggered off the birth of our solar system? Perhaps the answer lies in the meteorites.

In 1960 a physicist named John Reynolds at the University of California in Berkeley, was measuring the isotopic composition of the rare gas xenon which he had extracted from the Richardton chondrite. To his surprise he found that the proportion of one of the isotopes of xenon—^{129}Xe—was approximately 50% greater than that of ^{129}Xe from the earth's atmosphere (Reynolds 1960). He realised that the excess ^{129}Xe had come from the decay of the radioactive parent ^{129}I which no longer exists on earth because its half life is only 17 m.y. Thus if ^{129}I is synthesised in stars it would disappear after about 170 m.y. (or 10 half lives). Reynolds concluded that if the decay product of ^{129}I was present in meteorites as ^{129}Xe, then the meteorites must have formed into solid objects less than 170 m.y. after ^{129}I had been synthesised in stars. In other words, the birth process itself was relatively short—certainly less than 170 m.y.

Subsequent work with another short-lived radionuclide ^{26}Al (half life 0.72 m.y.) has shown that condensation of nebular gas took no longer than 10 m.y.. We also believe it was these short-lived radioactive nuclides that provided the heat necessary to melt the meteorite parent bodies and allow gravitational separation to occur. (Lee *et al.* 1977).

In the last few years some exciting discoveries have been made by examining the isotopic composition of elements from the high temperature inclusions in the carbonaceous chondrite Allende, which fell in Mexico in 1969. It has been found that many elements extracted from the Allende inclusions have an anomalous isotopic composition in comparison to other meteoritic or terrestrial material, and this has stimulated astrophysicists to consider new models for the formation of the solar system (Begemann 1980). The evidence now points to the fact that a supernova explosion may have "triggered off" the birth of the solar system. In fact some scientists believe that the Sun was born amidst a fireworks of supernova explosions, presumably connected with the passage of one of the spiral arms of our Galaxy through the region of space from which the Sun originated. The various isotopes of the elements synthesised by a variety of nuclear processes in supernova explosions have been well mixed into a homogeneous pool of isotopic composition throughout most of the solar system, but in the primitive high temperature inclusions in Allende, we can start to unravel the very nuclear processes which gave us birth.

Western Australian meteorites

In 1892 a rare iron meteorite was recovered near Ballinoo on a tributary of the Murchison River. Subsequently a similar meteorite was found in 1916 near Mount Magnet. This latter specimen has a unique horseshoe-shaped form. At the time of their discovery both Ballinoo and Mount Magnet were unusual in that they contained a high concentration of nickel (9.86% and 14.71% respectively). Subsequently the Warburton Range meteorite was discovered and found to contain 18.14% nickel (de Laeter 1973b).

The discovery of the Bencubbin stony-iron meteorite (which was recovered from a field during ploughing in 1930 and was followed by a second find in 1959), gave Western Australia a meteorite of extreme rarity and scientific importance. It contains chondritic material as enclaves in a host that consists of clinoenstatite and olivine enclosed in a metal reticulation which reveals a strong directed fabric suggestive of crystallisation under directed pressure (McCall 1968).

Another ususual mesosiderite is Mount Padbury which was found by W. C. Martin in 1964. Mount Padbury is a polymict breccia containing large olivine crystals together with achondritic enclaves (McCall 1966). This is the second greatest mass of mesosiderite material ever recovered, some 272 kg having been found.

The Mount Egerton meteorite is also an unusual meteorite in that it could be regarded as an achondrite with metallic inclusions, but some of the material is metal with silicate inclusions. When a section of the metallic phase is polished and etched, it gives a curious "ruled" etch pattern which is thought to be due to the presence of a nickel iron silicide (McCall 1965).

Another unusual iron meteorite is Redfields, which is a brecciated phosphide-rich meteorite (de Laeter *et al.* 1973). The high phosphide content has apparently inhibited Widmanstätten pattern development so that although the nickel content is 6.65% no taenite is present. Furthermore the meteorite has graphite inclusions, about 1 mm across, distributed throughout the metal giving it a "raisin-bread" appearance. The unusual structure of this meteorite is thought to be due to such factors as high carbon and phosphorus content and relatively rapid cooling.

One of the most impressive meteorites which has been recovered in Western Australia in recent years is the Mt. Manning iron. Weighing 701 kg it was discovered in 1979 at a site some 3 km east of the Mt. Manning Range. The meteorite has a fan-like or delta-wing shape as illustrated in Figure 3. One side of the specimen is smooth, slightly concave with a characteristic fusion crust, whereas the other sur-

Figure 3.—The Mount Manning iron meteorite displaying the rough, convex-shaped surface which contains numerous well-defined regmaglypts. The jagged, ablated trailing edge of the meteorite is distinguished by the fact that a sample has been cut from this portion of the meteorite (Scale = 30 cm).

face is convex-shaped, pitted with regmaglypts and extremely rough. It has been postulated (de Laeter 1980), that the meteorite performed a delta-wing like flight at a high angle of attack through much of the Earth's atmosphere in a stable aerodynamic configuration. In this descent path the underside of the meteorite was smoothed by atmospheric ablation, whereas the upper surface did not experience extensive melting. The thin trailing edge of the meteorite has been affected by heat as evidenced by its jagged appearance perforated in some places by holes.

An X-ray fluorescence spectrometric examination of the chemical composition of the Mt. Manning meteorite revealed that it belonged to the rare 1C class of iron meteorites (Thomas and de Laeter 1972). However in the Western Australian Museum collection there were two other meteorites, named Gosnells and Mt. Dooling, both belonging to the Group 1C classification. De Laeter *et al.* (1972) had previously shown that the 1.6 kg mass found at Gosnells was part of the Mt. Dooling meteorite, which had been found in 1909. Further examination showed that Gosnells and Mt. Dooling were both members of the Mt. Manning meteorite fall. It is believed that the original meteorite was travelling in a south-westerly direction and fragmented near the Mt. Manning Range. Presumably the Gosnells fragment was transported by human agency. It is possible that other specimens will be found in the vicinity of the Mt. Manning Range.

No discussion of Western Australian meteorites, no matter how brief, would be complete without some mention of the Mundrabilla meteorite shower, which contains the largest meteorites ever found in Australia, and one of the largest found anywhere in the world. Two large masses, weighing 11 000 kg and 5 000 kg were discovered some 182 m apart approximately 16 km north of Mundrabilla Siding on the Nullarbor Plain in 1966 by R. G. Wilson and A. M. Cooney.

Mundrabilla No. 2 was originally transported to the finder in Adelaide, but was later sent to the Max-Planck Institut für Kernphysik at Heidelburg where several slices were cut under the supervision of Professor P. Ramdohr. These slices were made available for display in various institutions around the world and one such slice is on display at the W.A. Museum. A small cut piece and the remains of the main mass are held by the South Australian Museum. The main mass of Mundrabilla No. 1 (11 000 kg), is on display in the W.A. Museum.

More recently Mr A. J. Carlisle found another two large specimens of Mundrabilla at a location some 20 km east of the site where Mundrabilla No. 1 and 2 were found. Figure 4 shows Mr Carlisle standing alongside the 840 kg specimen of Mundrabilla No. 3 in its original location in the Nullarbor Plain. Both Mundrabilla No. 3 and 4 are now on display at the Museum. De Laeter and Cleverly (1983) have recently analysed the Mundrabilla specimens and described their discovery. The meteorites were coated with a crust of iron oxides and surrounded by innumerable small, knuckle-shaped fragments which had been shed in flight due to ablation of the main masses. This is due to the fact that the Mundrabilla meteorites contain a significant amount of troilite, much of which was burnt out in the meteorite's passage through the atmosphere. Thus the characteristic feature of the Mundrabilla meteorites is the deep cavities which can readily be observed in the surface.

One of the most remarkable meteorite discoveries occurred in the early 1960's when two extremely rare achondrites, called ureilites, were found within a small area on the Nullarhor Plain. This increased the total number of ureilites from three to five. The two meteorites, named North Haig and Dingo Pup Donga were shown to be different meteorites even though they were found within 30 km of each other (Mason 1974).

Figure 4.—The 840 kg mass of Mundrabilla No. 3 iron meteorite. The finder, Mr A. J. Carlisle, is in the photograph which depicts the featureless nature of the Nullarbor Plain.

Another unusual chondrite named Coorara was also found close to Dingo Pup Donga in 1966. At the time this was only the second meteorite of its type known. This meteorite contains in veins formed either in the parent body or by shock in orbital collision of meteoroids or by shock on atmospheric entry, the high pressure minerals ringwoodite and majorite (McCall and Cleverly 1968). These high temperature minerals are of importance to our understanding of planetary bodies.

Conclusion

Meteorites have played, and will continue to play, a crucial role in our understanding of the formation and evolution of the solar system. The most important reason for this is that they stand alone among objects accessible for study as relics of the earliest stages of the solar system. The carbonaceous chondrites in particular, are thought to represent pristine material which has survived, essentially unaltered, during the past 4.6 billion years of solar system history. Samples of these meteorities have provided information on the chemical composition of the elements, and inclusions from some of them have given evidence of nucleosynthetic processes which indicate the possibility of a supernova trigger to the birth of the solar system. Even the more evolved iron, stony-iron and achondritic meteorites formed early in the solar system's history, probably before the oldest known terrestrial and lunar rocks.

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Although the six Apollo missions to the lunar surface provided scientists with a precious store of extra-terrestrial materials in the early 1970's, meteorite research is extremely vigorous today, in part because of the fact that lunar studies revealed the importance of meteorities to planetary science. The facilities and techniques which were established during the "Apollo era" have however, contributed to the research effort on meteoritics which has occurred over the past decade.

In recent years an enormous number of meteorites have been found in Antarctica (Cassidy and Rancitelli 1982). The initial discovery was made in 1969 by a Japanese team of glaciologists measuring ice movement at the Yamato Mountains in Enderby Land, whilst a second recovery has been made at Allan Hills in Victoria Land by a combined U.S.-Japanese team. Approximately 4 000 specimens have so far been recovered from Yamato Mountains and about 850 in south Victoria Land. These specimens may perhaps represent 500 or so distinct meteorites and thus increase the world's stock of these precious materials by about 25%, and the search is continuing. The Antarctic environment is so cold, dry and uncontaminated that this great cache of meteoritic material will undoubtedly extend our present knowledge of meteoritics.*

Another exciting discovery in recent years has been the possibility that the extinction of dinosaurs and numerous other species some 65 million years ago at the Cretaceous-Tertiary boundary may have been caused by a gigantic meteorite impact (Smith 1982). It has been shown that the concentrations of a number of elements (such as iridium, osmium, gold and palladium), are greatly enhanced in a layer of clay at the Cretaceous-Tertiary boundary in a number of locations in different parts of the world. These elements are extremely rare in the Earth's crust, but comparatively rich in meteoritic material, and it will be of interest to see if the meteorite impact hypothesis survives the numerous tests that will undoubtedly be carried out in the near future.

The meteorites which have been recovered from the deserts and farmlands of Western Australia represent a rich store of extraterrestrial material which have been used extensively by scientists both within Australia and overseas, to study various aspects of the formation and evolution of the solar system. Meteorites are survivors from the Asteroid belt which have landed on the Earth's surface, and been discovered by observant men and women, in most cases many years after their fiery descent through the Earth's atmosphere. The Western Australian Meteorite Collection is a tribute to those people who, realising that these objects are of special significance and part of our common heritage, have unselfishly reported their occurrence and assisted in their recovery.

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* There is now evidence that some of the Antarctic meteorites are actually fragments from the surface of Mars.